

PATENT SPECIFICATION

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(54) OPTICAL DEVICE

(71) We, F. HOFFMANN-LA ROCHE & CO. AKTIENGESSELLSCHAFT, of 124-134 Grenzacherstrasse, Basle, Switzerland, a Swiss Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an optical device having a rotative optical activity which is controllable by an electric field.

Some known optical devices use the "dynamic scattering effect" (see for example British Patent No. 1167486). Such known devices essentially comprise a capacitor having transparent plates and a dielectric mass of a nematic substance. An electric current flows through the capacitor and its moving charge carriers produce turbulence in the nematic substance. Since nematic substances are optically anisotropic, light reaching the liquid crystal through the transparent capacitor plates is scattered by the turbulence, thus altering the transparency and/or reflection of the device.

Optical devices using the "dynamic scattering effect" cannot be used in cases where high demands are made on the optical homogeneity of the device, since the turbulence of the liquid causes trouble in such cases. A further disadvantage is that the scattering destroys the coherence and polarisation of the incident light, so that laser light, for example, cannot be modulated by a dynamic scattering device without destroying the aforementioned properties. The relatively high threshold voltage of approximately 5V and the likewise relatively high voltage of approximately 20V at which the light-scattering reaches saturation are also disadvantageous in many applications—for example battery operation—in which the power supply components need to be small. Finally, the working life is probably closely dependent on the ion transport through the nematic substance (i.e. the life is shortened in proportion to the size of the current through the device).

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According to the invention, there is provided an optical device having a rotative optical activity which is controllable by an electric field, comprising a liquid crystal, including a compound which per se possesses a nematic phase and has a positive dielectric anisotropy, disposed between two plates and a polariser positioned for transmitting incident light to the liquid crystal when in use, in which device at least one plate is transparent for transmitting incident light to the liquid crystal when in use, the surface of at least one of the plates facing the liquid crystal is adapted to orientate the immediately adjacent liquid crystal molecules in a predetermined direction parallel to the plate, and the liquid crystal has a helical structure in the direction perpendicular to the plates.

The surfaces of the plates may be brought into a state exerting an orienting force on the molecules immediately adjacent to the plates, i.e. on the boundary layer of the liquid crystal, by, for example, rubbing the surface of the plate with a cotton plug.

The liquid crystal includes a nematic compound. Nematic liquid crystals have a parallel structure, i.e., their molecules when in the uninfluenced state are oriented substantially in a preferential direction parallel to one another.

If a nematic liquid crystal is disposed between two plates which exert an orientating force in the same direction on the boundary layer of the liquid crystal, the crystal structure assumes a preferential direction parallel to the wall orientation. If the two plates are rotated with respect to one another, the boundary layers adhere to the surfaces of the plates. Between the boundary layers, the orientation of the nematic molecules is such as to produce a continuous transition from one to the other direction of orientation. It is found that the nematic molecules are helically oriented along any line perpendicular to the plates.

A helical structure of the aforementioned kind in the liquid crystal can also be obtained by adding a small quantity of cholesteric

liquid crystalline or other optically active substance to the nematic liquid crystal. Cholesteric liquid crystals have a helical structure even in the uninfluenced state. When they are added to a nematic liquid crystal, they "induce" a helical structure therein, which helical structure is fixed at the surface of at least one of the plates by the orientating force exerted by such surface.

A liquid crystal having a helical structure is optically active, i.e. the direction of polarisation of plane polarised light passing through it follows the turns in the helical crystal structure.

The optical activity of liquid crystals with positive dielectric anisotropy can be controlled by an electric field. If a sufficiently strong electric field is produced in the liquid crystal in the direction of the helix axis (i.e. perpendicular to the plates), the molecules, with the exception of the adhesive boundary layer, take up a position parallel to the field, so that the helical structure is destroyed and the optical activity disappears. When the field is switched off, the previous structure is restored.

In order that the invention may be readily understood embodiments thereof will now be described in more detail, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a model of a liquid crystal having a helical structure;

Figure 2 shows an electro-optical device with continuously controllable transmission;

Figure 3 is a graph of the transmission through a device embodying the invention, in dependence on the voltage applied to the plates; and

Figure 4 is a graph of the angle of rotation of the device shown in Figure 2, in dependence on the applied voltage.

Figure 1 diagrammatically shows the orientations of different layers of a liquid crystal having a helical structure. The helical structure is either produced by relative rotation of two plates (not shown) between which the liquid crystal is located, or is induced by adding cholesteric compounds. Boundary layer 1 is oriented in the y direction whereas boundary layer 2 is oriented in the z direction. In any given plane 3 between the boundary layers, the orientation is at an angle between the y and the z directions, depending on the distance from the boundary layers.

Figure 2 shows an electro-optical device for continuous control of transmission comprising an electro-optical cell 11 disposed between a polariser 12 and an analyser 13 parallel to polariser 12. Cell 11 is a plate capacitor and consequently comprises two plane-parallel plates or electrodes 14 and 15 disposed at a distance from one another, and a dielectric 16 between the plates.

The dielectric 16 consists of a nematic

liquid crystal having positive dielectric anisotropy (i.e. the dielectric constant along the longitudinal axis of the molecule is greater than the dielectric constant in the direction perpendicular thereto, $\epsilon_{11} > \epsilon_{22}$).

Electrodes 14, 15 comprise glass plates coated with SnO_2 on their surfaces adjacent the liquid crystal. The SnO_2 surfaces are treated so that the molecules of the liquid crystal in the boundary layer are oriented in a preferential direction with their longitudinal axes parallel to the surface of the electrodes.

When the cell 11 has been assembled, the preferential directions of electrodes 14, 15 are rotated with respect to one another. The molecules of the liquid crystal in the boundary layers become oriented in the preferential directions of the electrodes. The nematic molecules in between are oriented so as to produce a continuous transition from the preferential direction in the boundary layer of electrode 14 to the preferential direction in the boundary layer of electrode 15. The molecules of the liquid crystal are helically oriented along any given line perpendicular to the electrodes, with the pitch of the helical structure of the liquid crystal being greater than the distance between the electrodes.

It was found that the direction of polarisation of for example plane polarised light travelling through electrode 14 and polarised parallel to its preferential direction follows the orientation of the nematic molecules and coincides with the preferential direction of electrode 15 when it leaves cell 11 through electrode 15. When the preferential directions of electrodes 14, 15 are rotated with respect to one another by 90° , the direction of polarisation of the incident light is rotated through 90° .

Cell 11 is disposed between the polariser 12 and the analyser 13 so that the preferential direction of electrode 14 adjacent to polariser 12 is parallel to the direction of polarisation of the polariser 12. If, therefore, the preferential directions of electrodes 14, 15 are at 90° to one another, the preferential direction of electrode 15 is perpendicular to the direction of polarisation of analyser 13. Consequently, light travelling from a source 17 through polariser 12 is polarised in the direction of the Z co-ordinate shown, travels through electrode 14 into the liquid crystal 16, is continuously rotated in the y direction on its path through the crystal, leaves cell 11 through electrode 15 and is not transmitted by analyser 15, which is oriented in the z direction. Consequently, an observer 18 does not see any light from source 17.

On the other hand, if analyser 18 is rotated 90° with respect to polariser 12, the light from source 17 reaches the observer 18.

If a voltage is applied to electrode 14, 15,

i.e. if an electric field perpendicular to the electrodes is produced in the liquid crystal, a torque acts on the nematic molecules since $\epsilon_{11} > \epsilon_{\perp}$ and tends to move the longitudinal axes of the molecules in the direction of the fields. As the voltage at the electrodes increases, the orientation becomes closer and closer to the direction of the field vector until it is practically parallel thereto, when the voltage is sufficiently high. Simultaneously, the helical structure disappears and the optical activity of the liquid crystal practically disappears also. Polarised light entering through electrode 14 leaves cell 11 without any change in its direction of polarisation. After the voltage has been switched off, the helical structure of the liquid crystal is restored by the orientating force of the surfaces of electrodes 14, 15.

If a voltage is applied to the electrodes of the device of Figure 2 in which the planes of polarisation of polariser 12 and analyser 13 are parallel, the polarised light is partly or completely transmitted to the observer 18, depending on the strength of the voltage. If the polariser and analyser are crossed and the voltage is sufficiently high, no light from source 17 reaches observer 18.

Figure 3 shows the transmission, depending on the voltage applied to the electrodes, of a device of the aforementioned kind in which the directions of polarisation of the polariser and analyser are parallel. It can be seen that the transmission is approximately zero if no voltage is applied. When the voltage increases, the transmission at first remains approximately zero until a certain threshold voltage is reached, depending on polarisation phenomena. Above the threshold voltage, the transmission continuously rises until a form of saturation is reached.

The optical activity can be controlled either by a d.c. or a.c. voltage. The preferred method of operation depends on the application. With a.c. voltage operation, the threshold voltage is particularly low since polarisation phenomena are avoided. The curve shown in Figure 3 is independent of frequency up to approximately 80 kHz.

The liquid crystal used in the device was made of N(4' - ethoxybenzylidene) - 4 - aminobenzonitrile (PEBAB). Of course, substantially the same results can be achieved by using any other nematic substance with positive anisotropy, i.e. with $\epsilon_{11} > \epsilon_{\perp}$. In the cell, the electrode surfaces have an area of about 4 cm². The liquid crystal is 10--100 μ thick.

The following results obtained with the aforementioned device clearly show the superiority of a device embodying the invention over a corresponding electro-optical device based on the "dynamic scattering effect".

The polarisation of incident light remains practically unaltered, so that devices embody-

ing the invention are also suitable e.g. for modulating laser light. The threshold voltage at which the electro-optical effect occurs is about 1 V for a.c. and approximately 2.5 V for d.c. voltage; the saturation voltage is approximately 4 V for d.c. and a.c. voltage. The power consumption for d.c. operation is considerably lower than in dynamic scattering devices. Finally, the service life is very long because of the low transport of charge carriers.

A large number of modifications can be obtained to achieve various advantageous effects. For example, a chromatic or coloured liquid crystal in cell 11 can be used in conjunction with two polarisers to produce a device which is opaque when no voltage is applied and which is transparent to only one colour when voltage is applied. The reverse effect can also be achieved. In the transition region there are corresponding shades between black and the chosen colour.

Cell 11 can also be used in a reflection mode. To this end, the analyser 13 (e.g. in the form of a film) disposed behind the cell is adhesively secured to a conventional mirror. Light falling on the mirror is either reflected or absorbed, depending on whether a voltage is applied to the cell.

Because of its properties, a device embodying the invention is suitable for numerous applications. Since coherence is maintained, the device can be used as an element in a page-composing matrix for a hologram store. As is known, a matrix of the aforementioned kind comprises a large number (e.g. 10⁴) of elements which, depending on the control, are opaque or transparent to coherent light and can thus be used for writing a bit in the store. More particularly, such a matrix can be addressed. To this end, the liquid crystal is disposed between two plates whose conductive coating is divided into a number of strips insulated from one another, so that the directions of the strips on one plate are perpendicular to those on the other plate. A voltage can be applied to the strips by suitable connections so that individual segments can be addressed.

In addition to the aforementioned special application, the devices can be used in general for modulating the intensity of light, in which case the low control voltages are particularly advantageous.

Since the light beam can be extinguished, in contrast to dynamic scattering devices, electro-optical shutters can be produced. The direction of the plane of polarisation of plane polarised light can be electronically controlled and modulated (e.g. for polarimetry). There are further applications to television and data processing (the recording of optical and electric signals).

The device can also be applied to the production of spectacles having an absorp-

tion which is controlled by the intensity of the incident light.

WHAT WE CLAIM IS:—

1. An optical device having a rotative optical activity which is controllable by an electric field, comprising a liquid crystal, including a compound which per se possesses a nematic phase and has a positive dielectric anisotropy, disposed between two plates and a polariser positioned for transmitting incident light to the liquid crystal when in use, in which device at least one plate is transparent for transmitting incident light to the liquid crystal when in use, the surface of at least one of the plates facing the liquid crystal is adapted to orientate the immediately adjacent liquid crystal molecules in a predetermined direction parallel to the plate, and the liquid crystal has a helical structure in the direction perpendicular to the plates.
2. An optical device according to claim 1, wherein the liquid crystal contains a cholesteric compound.
3. An optical device according to claim 1 or 2, wherein both plates are transparent.
4. An optical device according to any one of claims 1 to 3, wherein the surfaces of the plates facing the liquid crystal are made of a conductive material, and connections are provided for applying a voltage to the plates.
5. An optical device according to claim 1, wherein the pitch of the helical structure of the liquid crystal is greater than the distance between the plates.
6. An optical device according to any one of the preceding claims comprising a polariser

disposed to receive light transmitted through the liquid crystal.

7. An optical device according to claim 6, wherein the two polarisers are oriented parallel to one another.

8. An optical device according to claim 6, wherein the two polarisers are crossed.

9. A method of continuously controlling the rotation of the plane of polarisation of plane polarised light by means of a device according to any one of claims 1 to 8, in which method an electric field perpendicular to the plates is produced in the liquid crystal.

10. A method according to claim 9, wherein the field is of a single polarity.

11. A method according to claim 9, wherein the field is an alternating field.

12. A write-in matrix for writing data into a hologram store and including a device according to claim 1.

13. An optical device substantially as hereinafore described with reference to, and as illustrated in, the accompanying drawings.

14. A method of continuously controlling the rotation or the plane of polarisation of plane polarised light substantially as hereinbefore described with reference to the accompanying drawings.

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SPECIFICATION NO 1372868

By a direction given under Section 17 (1) of the Patents Act 1949 this application proceeded in the name of BBC BROWN, BOVERI & COMPANY LIMITED, a Swiss Company, of Patentabteilung, CH-5401, Baden, Switzerland and F. HOFFMANN-LA ROCHE & CO AKTIENGESELLSCHAFT, a Swiss Company, of 124-184 Grenzacherstrasse, Basle, Switzerland.

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2. An optical device according to claim 1, wherein the liquid crystal contains a cholesteric compound.

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10. A method according to claim 9, wherein the field is of a single polarity.

11. A method according to claim 9, wherein the field is an alternating field.

12. A write-in matrix for writing data into a hologram store and including a device according to claim 1.

13. An optical device substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.

14. A method of continuously controlling the rotation of the plane of polarisation of plane polarised light substantially as hereinbefore described with reference to the accompanying drawings.

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